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PROCESS FOR IMPROVING THE MAGNETIC PROPERTIES OF SILICON STEEL

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Fig. 1.

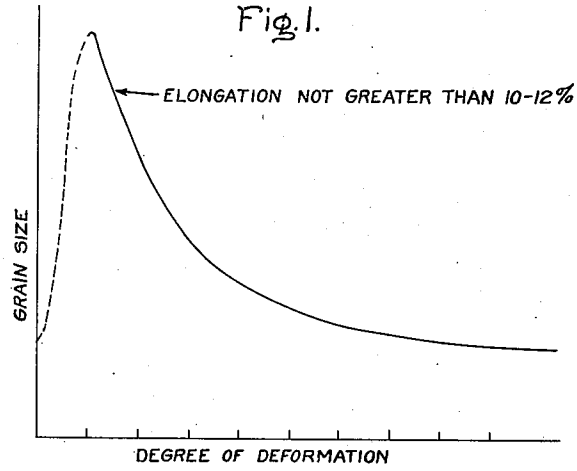
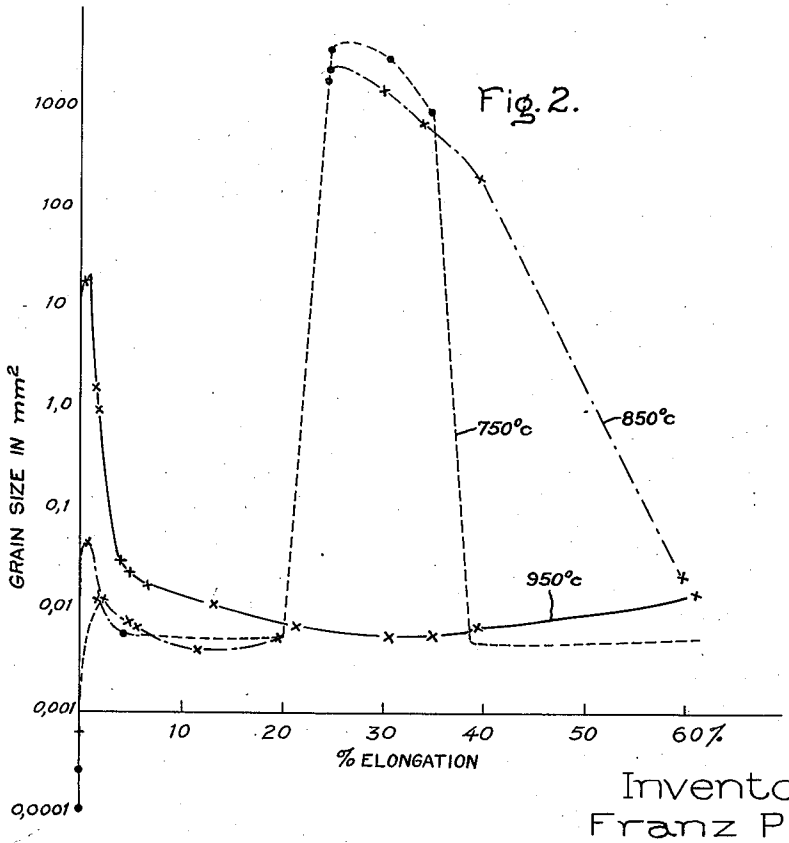


Fig. 2.



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PROCESS FOR IMPROVING THE MAGNETIC PROPERTIES OF SILICON STEEL

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3 Claims. (Cl. 148—12)

The present invention relates to magnetic material and more particularly to a method for improving the magnetic properties of such material.

It is one of the objects of the invention to provide an improved magnetic material having a large grain size. A further object of the invention is the provision of means whereby the final cold reduction of large grain size magnetic material may be varied within comparatively wide limits without causing substantial change in grain size.

The novel features which are characteristic of our invention are set forth with particularity in the appended claims. The invention itself however will best be understood by reference to the following specification and appended claims when considered in connection with the accompanying drawing in which Fig. 1 is a recrystallization diagram for metals generally, while Fig. 2 represents a series of crystallization diagrams for silicon steel illustrating features of the present invention.

The structure of a metallic work-piece, as is well known, can be varied considerably by deformation in conjunction with recrystallization. These conditions may be represented in a recrystallization diagram, in which the size of the grain is plotted in dependence upon the degree of deformation (reduction of thickness to a percentage of the initial thickness) and annealing temperature.

The dependence and thus the method of influencing the size of the grain at will seemed clearly determined by previous experiments. For all metals and alloys there is obtained in principle the same recrystallization diagram as shown in Figure 1. This figure as hereinbefore set forth represents a section from the space diagram: size of grain—degree of deformation—for a constant recrystallization temperature. A maximum grain size is obtained by a certain degree of deformation which occurs with small reductions in thickness, the so-called critical degree of stretch or elongation.

This critical degree of elongation is a result of the influence of cold elongation upon the crystallization property. In this case it is best to distinguish between the recrystallization capacity and recrystallization nuclei. Both are first brought about by cold deformation, each being enlarged or multiplied by increasing cold deformation. The critical elongation or stretching degree at which the largest grain is uniformly obtained in the whole work-piece is characterized by the fact that the capacity for recrystallization of the work-piece in all its parts and crystals is brought about with the smallest number of nuclei or starting points of recrystallization.

With an increased degree of elongation the number of nuclei is greater and the recrystallization commences at a greater number of points. As a result the size of grain decreases since the growth ceases with the coming together of the individual newly-growing grains. In the range below the critical elongation no uniform recrystallization of the work-piece is possible since the deformation necessary for obtaining the recrystallization property is not exceeded in all parts of the work-piece. Therefore no uniform grain is found here. Regions with large new crystals alternate with regions of small initial crystallites which are probably still unchanged. In Figure 1, for this reason, this part of the curve is shown as a dotted line. The form of the curve under consideration applies for all temperatures above the recrystallization temperature; with increasing temperature the curve is only displaced to larger grain dimensions and the position as well as the sharpness of the peak may change to a small extent.

As already mentioned above, the course of the curve for the degree of elongation or stretching related to the size of grain, or the space diagram: grain size, stretching degree, recrystallization temperature, derived from the tracing of such curves for different temperatures, applies under all conditions, according to all previous investigations. According to the size of the initial crystals or the nature of the material the critical stretching degree may vary to some extent, but cases are not known where it amounts to more than 10–12%, and in all cases it is a fact that to obtain a grain of the largest possible size the critical elongation of stretching degree must be observed as strictly as possible (up to about $\frac{1}{10}$% reduction in thickness).

The knowledge of this recrystallization diagram has been of the greatest importance for metal working. On the one hand, it enables us to avoid operations which produce a coarse structure which may be harmful in the case of structural materials subjected to compressive stress. On the other hand, it indicates the manner of obtaining a coarse structure in an ideal case, even of a mono-crystalline work-piece. If the great scientific interest in mono-crystals is disregarded, the main interest in such enlargement of the grains is in connection with magnetic materials. In this case it was recognized that with the in-

crease in size of grain a considerable improvement occurs, i. e. a decrease in the coercive force and hysteresis losses and an increase in the permeability. For such improvements the methods prescribed by the recrystallization diagram were intentionally used. The difficulty in their application was that the reduction of thickness to be effected was small and had to be maintained very accurately, since any upward or downward variation caused a disturbance of the coarse crystallization either a general considerable decrease in size or incompletely recrystallized regions that still remained. Such a close regulation of the reduction in thickness, by rolling, is possible only with difficulty in the case of large dimensions of the metal sheets which, with the preliminary rolling and large dimensions of the rolls never receive absolutely equal thickness over the entire width.

The present invention is based on the observation that the recrystallization diagram represented in Fig. 1 is restricted by certain conditions. The process forming the subject of the present invention whereby coarse crystallization in metallic materials is obtained, consists in subjecting such materials to cold deformation above the "critical degree of elongation" before final annealing. This cold deformation should be greater than 15%. The most favorable degree of elongation also depends upon the space lattice or the composition of the material. In the case of silicon steel the range between about 20 and about 40% has proved to be particularly suitable. This last cold deformation is followed by a final anneal at elevated temperatures which are preferably higher than 950° C. and are chosen preferably in the range between 950° C. and 1100° C. when using silicon steel and in general are at least 300° C. above recrystallization temperature. By means of such a treatment considerable grain enlargement and thus improvement in the magnetic properties of the treated materials are obtained, the grain enlargement being greater than that obtained by using the critical stretching degree. The process according to the present invention has the further advantage that the final degree of elongation can be varied within comparatively wide limits without a substantial change occurring in the grain enlargements obtained, a fact which greatly facilitates and reduces the cost of manufacture.

In addition to the final elongation and the final annealing, the preceding stages of treatment applied to the material also have a certain influence on the size of grain obtained. Thus, it is preferable to choose for the preliminary elongation a cold deformation which is not too small. It is preferable not to fix the preliminary elongation below a 15% reduction in thickness. An upper limit does not exist in the case of the preliminary elongation but the grain enlargement can be increased within certain limits by increasing the preliminary elongation. The temperature of the anneal between the preliminary elongation and the final elongation is preferably chosen not too high and for best results should be as little as possible above the recrystallization temperature and at most not more than 400° C. above the recrystallization temperature. By preliminary annealing at excessive temperature the total result may become doubtful since thereby a coarse grain is produced which is unfavorable at this stage.

In Figure 2 the dependence of the size of the grain upon the final elongation for silicon steel (2.8% Si) is represented for three different preliminary annealing temperatures. The alloy was made from Swedish iron and silicon in a high frequency furnace and rolled out into sheets in the hot or cold condition in conjunction with the annealing operations. The deformation for the recrystallization was also effected by rolling. The final thickness amounted for all sheets to 0.3 mm., as is usual in transformer construction. In the individual results shown the following are kept constant: (1) the last recrystallization temperature and time: 4 h. 1025° C.; (2) the next to the last cold elongation 75%. The following are varied: (1) the annealing temperature employed before the last cold stretching: 750° C., 850° C. and 950° C.; (2) the final elongation. The result is plotted in accordance with the curve referred to at the beginning. All the curves at first take the hitherto well-known course; considerable coarseness of the grain being obtained by a low critical degree of elongation then a decrease of the size of the grain. In the case of the specimen previously annealed at 950° C. this course remains practically unchanged up to the highest degree of elongation. In the case of the specimens previously annealed at 850° C. and 750° C. with about 20% elongation, on the other hand, there occurs a sudden rise of the curve to very great dimensions of the grain. This size of the grain is maintained over a comparatively large range of elongation and then falls again very quickly to small dimensions.

The course of the curves is, of course, different for different materials. It is also possible in the case of one and the same material to choose different individual stages of treatment in accordance with the actual circumstances, for example, in one case the effect of the preliminary degree of elongation on the size of the grain may be employed and in the other case the effect of the preliminary annealing temperature may be employed. It can easily be ascertained from experiments which of the numerous variants available are the most favorable in each case. The treatment should in any case be chosen in such a manner that the recrystallization structure favorable for the abnormal growth is obtained. On the basis of previous tests this can be obtained with greater certainty the higher the preliminary elongation and the lower the preliminary annealing temperature and the higher the final recrystallization temperature.

A comparison of the magnetic qualities of metal sheets treated by the process according to the invention in the coarse crystalline condition, with the magnetic qualities of metal sheets having a fine structure showed for the latter in the case of a size of grain of 0.0056 mm.^{2} a watt loss of 1.5–1.6 W/kg., while the former in the case of a size of grain of 3850 mm.^{2} showed a watt loss of only 0.7–0.9 W/kg.

The use of the process according to the invention for obtaining mono-crystals or a coarse macro-crystalline structure, however, is not limited to the iron silicon alloys described, but can also be used for other materials in the same manner. The degree of elongation and annealing temperatures actually most favorable can be determined without difficulty in each case by tests.

What we claim as new and desire to secure by Letters Patent of the United States is:

1. The process for improving the magnetic properties of silicon steel which comprises cold rolling the steel to effect a reduction in thickness

of more than 15%, annealing the steel at a temperature at which recrystallization takes place but below 950° C., cold rolling the steel to effect a reduction of 15% to 45% in thickness and finally annealing the steel at a temperature between 950° C. and 1100° C., said first mentioned anneal and last reduction being such that the product after said final anneal exhibits a structure of large macro-crystals.

2. The process for improving the magnetic properties of silicon steel which comprises cold rolling the steel to effect a reduction in thickness of more than 15%, annealing the steel at a temperature between about 750° C. and 850° C., cold rolling the steel to effect a reduction of about 20% to 40% and finally annealing the steel at a temperature between 950° C. and 1100° C.

3. The process for improving the magnetic properties of silicon steel containing about 3% silicon which comprises cold rolling the steel to effect a reduction of 75% in thickness, annealing at a temperature between 750° C. and 850° C., cold rolling the steel to effect a reduction of about 20% to 40% in thickness and annealing the steel at a temperature in the neighborhood of 1025° C.

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